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# Evolution and appearance of Be stars in SMC clusters

**C. Martayan[1,2], D. Baade[3], Y. Frémat[4] and J. Zorec[5]**

[1] European Organisation for Astronomical Research in the Southern Hemisphere, Alonso de Cordova 3107, Vitacura, Casilla 19001, Santiago 19, Chile
email: `cmartaya@eso.org`

[2] GEPI, Observatoire de Paris, CNRS, Université Paris Diderot, 5 place Jules Janssen, 92195 Meudon Cedex, France

[3] European Organisation for Astronomical Research in the Southern Hemisphere, Karl-Schwarzschild-Str. 2, 85748 Garching b. München, Germany

[4] Royal Observatory of Belgium, 3 avenue circulaire, 1180 Brussels, Belgium

[5] Institut d'Astrophysique de Paris, UMR7095, CNRS, Université Marie & Pierre Curie, 98bis Boulevard Arago 75014 Paris, France

**Abstract.**
Star clusters are privileged laboratories for studying the evolution of massive stars (OB stars). One particularly interesting question concerns the phases, during which the classical Be stars occur, which unlike HAe/Be stars, are not pre-main sequence objects, nor supergiants. Rather, they are extremely rapidly rotating B-type stars with a circumstellar decretion disk formed by episodic ejections of matter from the central star. To study the impact of mass, metallicity, and age on the Be phase, we observed SMC open clusters with two different techniques: 1) with the ESO-WFI in its slitless mode, which allowed us to find the brighter Be and other emission-line stars in 84 SMC open clusters 2) with the VLT-FLAMES multi-fiber spectrograph in order to determine accurately the evolutionary phases of Be stars in the Be-star rich SMC open cluster NGC 330. Based on a comparison to the Milky Way, a model of Be stellar evolution / appearance as a function of metallicity and mass / spectral type is developed, involving the fractional critical rotation rate as a key parameter.

**Keywords.** stars: emission-line, Be, stars: fundamental parameters, stars: statistics, stars: early-type, stars: evolution, surveys, galaxies: star clusters, Magellanic Clouds

## 1. Observations, spectral analysis

We performed an Halpha survey with the ESO-WFI (Baade et al. 1999) in its slitless mode in the central parts of the SMC. Three million low-resolution spectra were obtained. They were extracted from the images with *Sextractor* (Bertin & Arnouts 1996) and we developed *Album* (Martayan et al. 2009)to identify the spectra presenting H$\alpha$-emission. After astrometric calibration, the extracted sources were cross-matched with the OGLE-II photometric catalogue (Udalski et al. 1998). Within the area observed, results for 84 SMC open clusters are presented. In particular, the results are compared with the ones from McSwain & Gies (2005) in Galactic open clusters. The ratios of clusters with and without of classical Be stars are compared w.r.t. metallicity (Z), spectral-type, and age. Observations were also carried out with the VLT-FLAMES (Pasquini et al. 2002) of the Be-star rich SMC open cluster NGC330 and its vicinity. LR2 spectra (395-455nm, R=6400, H$\epsilon$, H$\delta$, H$\gamma$, HeI447.1nm, MgII448.1nm) and LR6 spectra (650-770nm, R=8600, H$\alpha$) were aquired between October 2003 and September 2004. For each star, the fundamental parameters were determined with GIRFIT (Frémat et al. 2006), taking account of fast-rotation effects with FASTROT (Frémat et al. 2005). In particular, rotational

velocities were determined as well as the statistical fractional angular breakup velocity for Be stars of different ages (see Martayan et al. 2007).

## 2. Observed metallicity effect on the relative frequency of Be stars

The metallicity of the SMC is significantly lower (0.001<Z<0.009, Cioni et al. (2006)) than the one of the Galaxy (Z=0.020). Fig. 1 shows the fraction of Be stars to all B-type stars by spectral type, separately for SMC and MW. It clearly indicates that early-type Be stars are 3-5 times as frequent in the SMC as in the MW (beyond B2-B3, the SMC sample is incomplete). Note that the age ranges are comparable. The large difference in frequency is obviously most easily attributed to the difference in metallicity.

## 3. Appearance of Be stars in open clusters as a function of age

Fig. 2 displays the fraction of open clusters with Be-stars in SMC and MW vs. age. It appears that Be stars are preferrentially hosted by young open clusters. A first decrease in the fraction of open clusters with Be stars is seen around 30-40 Myears (corresponding to early-type Be stars reaching the TAMS) is followed by an increase of open clusters with Be stars. The terminal decrease in older open clusters is due to also the late-type Be stars arriving on the TAMS.

## 4. Metallicity-dependent evolution of rotational velocities

To explain the overall shape of Fig. 2, the temporal evolution of the fractional angular velocity ($\frac{\Omega}{\Omega_c}$) of Be stars can be reconstructed from observed rotational velocities (here we use VLT-FLAMES spectra) and theoretical evolutionary tracks from Maeder & Meynet (2001). From our SMC data and results obtained by Zorec et al. (2005) in the MW, Be stars have a minimal $\frac{\Omega}{\Omega_c}$ of 0.7. If/when B-type stars rotate more slowly, Be symptoms do not seem to develop.

The evolution of the $\frac{\Omega}{\Omega_c}$ depends on stellar mass and metallicity (see Fig. 5 from Martayan et al. (2007)), which holds the key to the understanding of the distribution seen

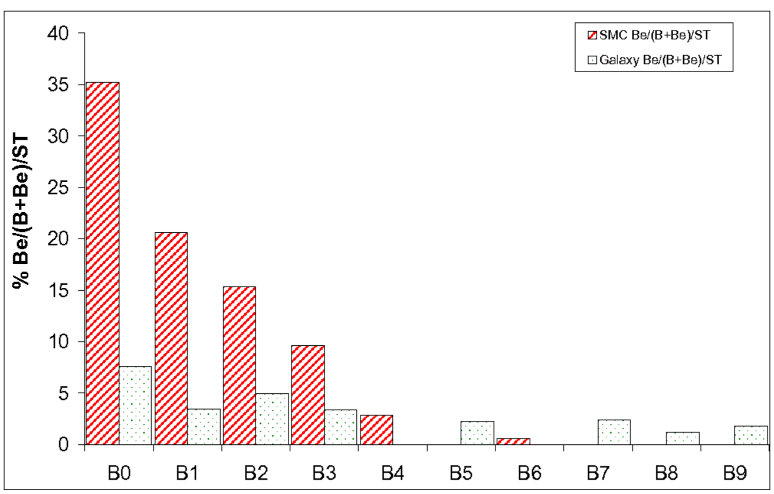


**Figure 1.** The relative abundances of Be stars in the SMC (hatched bars) and the Galaxy (dot-filled bars) as a function of spectral type.

in Fig. 2:

In massive MW Be stars, the $\frac{\Omega}{\Omega_c}$ sufficient for the development of Be star symptoms at the beginning of the Main Sequence. Due to wind-driven mass loss the angular momentum decreases until $\frac{\Omega}{\Omega_c}$ has dropped below the threshold of 0.7 and the initial Be-star appearance will be lost after ∼5-10 Myears. This can explain the small decrease observed in the MW for open clusters with Be stars as seen in the data of Mathew et al. (2008). Intermediate-mass Be stars seem to retain a sufficently high level of $\frac{\Omega}{\Omega_c}$ during their entire Main Sequence evolution to preserve their appearance as Be stars without interruption. They Be-stars attributes will eventually diseappear once the TAMS is reached at ∼ 40Myears, which can explain the lower fraction of Galactic open clusters with Be stars of this age.

Rapidly rotating low-mass B stars can appear as Be stars at the beginning of the Main Sequence but will lose this status quickly by a reorganization of the internal angular momentum. Later, the standard evolution of $\frac{\Omega}{\Omega_c}$ with time (increase of the radius with small angular momentum loss), will let them reach an $\frac{\Omega}{\Omega_c}$ above 0.7 so that at an age of 40-50 Myears they are again recognizeable as Be stars. This fact can explain the second increase of the number of open clusters with Be stars at an age 40 Myears. The low-mass Be stars will then begin to reach the TAMS and the number of open clusters with Be stars decreases with age.

In the SMC, the evolution of $\frac{\Omega}{\Omega_c}$ of intermediate- and low-mass Be stars is similar to the MW case because in this mass range mass-loss is too small to significantly alter the angular momentum or its internal distribution. This explains the evolution of open clusters with Be stars and ages between 30 and 100 Myears. Still older open clusters that host Be stars probably had multiple star-formation episods or the Be stars may be blue stragglers. Note that, for the MW, McSwain & Gies (2005) suspect that 75% of the Be stars are binaries.

The evolution of more massive Be stars is different in the SMC than in the MW. Because of the lower SMC metallicity, mass and angular momentum loss are lower as well, and $\frac{\Omega}{\Omega_c}$ will increase with the time as in low-mass Be stars. They will reach the 70%

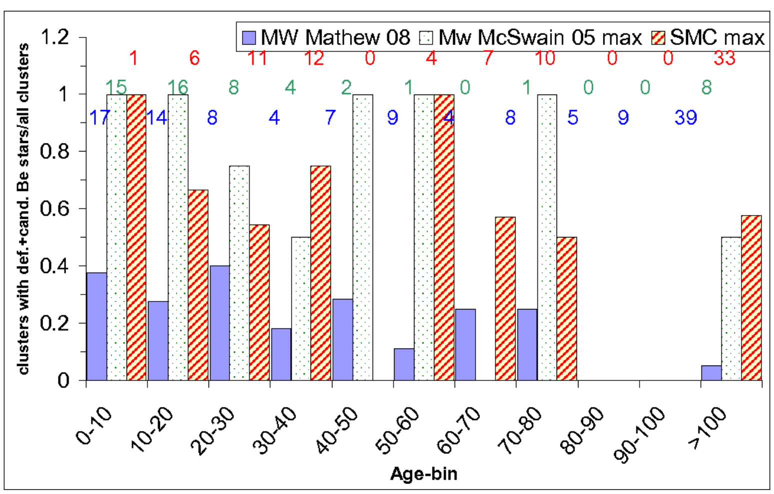


**Figure 2.** Fraction of open clusters with Be-star members in the SMC (hatched bars) and the MW (dot-filled bars: data from McSwain & Gies (2005), filled bars: data from Mathew et al. (2008)) as a function of cluster age. The number of clusters studied is given above each bar.

limit at $\sim$4-5 Myears and then again appear as Be stars, in contrast massive Be stars in the MW. Therefore, in the SMC very young open clusters are expected to contain Be stars.

However, for the observational verification of this difference in the fraction of Be stars between very young open clusters in MW and SMC a larger sample of open clusters younger than 10 Myears is needed. For such a comparison, one must careful discriminate between classical Be stars and Herbig Ae/Be stars, which are still on the pre-MS and owe their emission lines to their parental accretion disk. A method for this separation is described in Martayan et al. (2008).

The inferred long-term transitions between Be and B phases will not probably be abrupt, and one may speculate whether the much faster and repetitive Be to B and B to Be transformations observed in many Be stars are part of the long-term transitions. If so, one would expect that Be stars with stable and Be stars with more volatile circumstellar disks should not show gross differences otherwise. In fact, this is what McSwain et al. (2009), reported recently.

## 5. Conclusions

We conducted a study of open clusters with Be stars in two data sets:

- a low-resolution H$\alpha$ survey of 84 SMC open clusters. It indicates that Be stars are more abundant in the SMC than in the MW. The fraction of open clusters with Be stars reaches a local minimum at ages around 30-40 Myears and finally declines for clusters older than 70-80 Myears.
- Fundamental stellar parameters determined from medium-resolution spectra of B and Be stars in the SMC open cluster NGC330 and its vicinity allowed us to study the evolution of the fractional critical angular velocity, $\frac{\Omega}{\Omega_c}$, of Be stars. Its dependency on stellar mass and metallicity can explain the distribution with age of the fraction of open clusters with Be stars and the differences between Galaxy and SMC.

All data and a more comprehensive discussion are provided in Martayan et al. (2009).

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